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(NASA-TM-X-74170) PACKAGING OF A LARGE CAPACITY MAGNETIC BUBBLE DOMAIN SPACECRAFT RECORDER (NASA) 7 p HC A02/MF A01 CSCL 14B

N77-20404

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Rockwell International

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14 February 1977

Prepared for

COMPCON
IEEE Spring Computer Conference
Jack Tarr Hotel
San Francisco, CA
March 1977

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X77-11/201

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Foreword

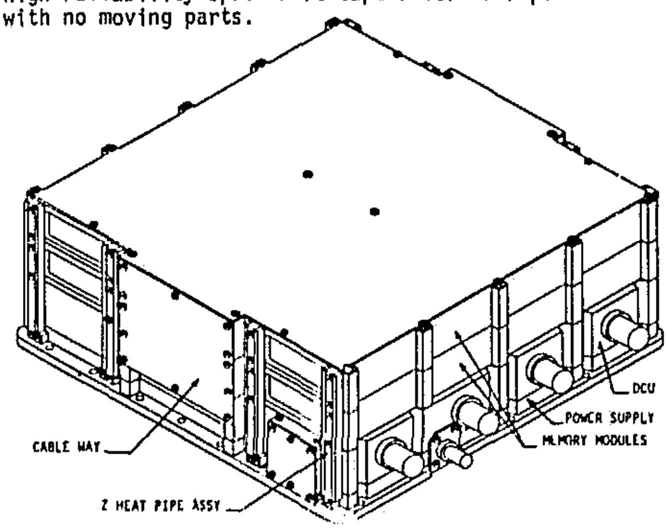
Data storage is a necessary function in most spacecraft whether it be mass data storage because information transfer links are inadequate, buffer type storage to regulate flow of information, or transient storage to permit processing and/or conditioning of data prior to transmission.

The most cost effective technology used for performing on board data storage functions is magnetic tape recording. Such recorders offer a combination on non-volatile storage, high speed and reasonable size and weight. Their chief disadvantages are low reliability and high cost.

It has been said that tape recorders are one of the most failure prone components in U. S. spacecraft. Recent studies of tape recorder performance on NASA missions reveal failures occur at rates which are of the order of 100 per 10^6 hours of operation. This level is unacceptably high in view of the criticality of the data storage function to mission success.

To solve this problem for future spacecraft and to reduce cost by standardization, NASA has undertaken the development of a versatile, high reliability tape recorder. Additionally, the high incidence of mechanical failures (about 70 percent of the total) point to a need for a new recording method with no moving parts.

Magnetic bubble domain memory technology has been chosen as a means to meet the long range goals of a high reliability spacecraft tape recorder replacement with no moving parts.



SOLID STATE SPACECRAFT DATA RECORDER (SSDR)
LENGTH 12.75 IN., WIDTH 12.70 IN., HEIGHT 5.30 IN.

Summary

A Solid State Spacecraft Data Recorder (SSDR), based on bubble domain technology, having a storage capacity of 10^8 bits, has been designed and is currently being tested at the Rockwell International Autonetics Group under contract to the NASA Langley Research Center.

The recorder consists of two memory modules each having 32 cells, each cell containing sixteen 100 kilobit serial bubble memory chips. The memory modules are interconnected to a Drive and Control Unit (DCU) module containing four microprocessors, 500 integrated circuits, a RAM core memory and two PROM's.

The two memory modules and DCU are housed in individual machined aluminum frames, are stacked in brick fashion and through bolted to a base plate assembly which also houses the power supply.

The SSDR weighs approximately 47 pounds, occupies 860 in^3 and is conduction cooled. Polymeric materials have been selected to meet thermal vacuum and heat sterilization requirements. Structural design is based on environmental and thermal considerations. Heat pipes are used extensively throughout the system to reduce weight and improve thermal performance.

Bubble Domain Device Fundamentals

The memory devices are constructed by placing garnet film into two low-level magnetic fields. One field, generated by a permanent magnet, is normal to the film and stabilizes the domain. The second field, generated by crossed coils, rotates in the plane of the field to cause the domains to move around permalloy patterns deposited on the films. The presence of a bubble domain on the periodic permalloy patterns constitutes a binary "1"; absence of a bubble domain constitutes a zero.

The bubble domain memory is, therefore, analogous to drum, disk, and tape memories, in that the stored data are moved past a read head or a detector. The bubble memories, however, offer solid-state reliability and greater system design flexibility.

Memory Element

The basic storage element for the SSDR is a serial bubble domain memory chip having 100 kilobit capacity, functions for writing (generator), reading (detector), erasing (annihilator) and noise cancellation (dummy detector).

The SSDR chip is produced from a two-inch diameter, .020 inch thick garnet wafer which has the necessary epitaxially grown doped garnet film with permalloy and aluminum etched depositions. At 100 percent yield, approximately 40 100 kilobit chips are available for use in the SSDR. The wafers are laser scribed and separated to produce individual chips. The resultant chip is .25 inch square and has eight interconnect pads on 25 mil centers located along one edge.

Cell Design Requirements

The cell assembly which houses the bubble domain memory chips is the most critical mechanical component in the system as the design must provide closely

controlled magnetic and thermal environments.

Early trade-off studies considered the following:

1. A rotating magnetic field in the X-Y plane of the chip is required to propagate the bubbles during the read, write, erase (detect, generate, annihilate) operations. This field would be generated by two orthogonal coils.

2. The preferred coil design would allow easy access to the bubble chips for whatever rework would be necessary after test.

3. The coil volume must be minimized in order to reduce power and the number of bubble chips per coil must be maximized but consistent with chip yield and matching considerations.

4. A uniform constant magnetic field (Z bias) through the chip Z axis must be provided in order to stabilize the magnetic domains in the devices.

5. The Z magnetic field must vary with chip temperature and therefore must be thermally tightly coupled to the bubble chip temperature. Temperature compensated rare earth permanent magnets would be used.

6. A constant X component of the Z bias field is required for reliable start-stop operation of the bubbles.

7. The Z bias field must be capable of being electrically altered for margin testing; thus a Z coil would be required.

8. The Z bias field must be held constant, shielded from external fields and must not produce significant stray fields which might affect other spacecraft instrumentation or interact with adjacent bias assemblies.

9. Some form of substrate would be required on to which the chips could be aligned, mounted, interconnected and cooled.

10. As the number of chips per cell is to be maximized, packaging two or more substrates would be considered.

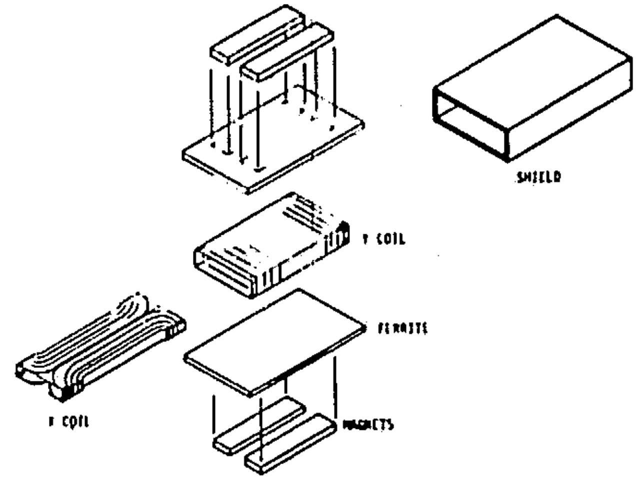
11. Interconnect of the detectors must be very uniform geometrically in order to minimize dØ/dt noise injection from the rotating magnetic field. Circuit line routing and impedances on the detector lines must be carefully designed in order to further reduce noise pickup.

12. The chip mounting substrate should be a good heat conductor as the operating temperature must be minimized with respect to ambient and closely track the magnet temperature.

13. Minimum weight and volume are required and thus strongly influence the overall design.

Cell

The cell design adopted for the SSDR consists of a magnetic assembly and final cell assembly which includes the chip carrier and mounting hardware. Cell capacity is 1.6 ˙ 0^6 bits, weighs .25 pound, and has a volume of 2.2 ,'



CELL MAGNETIC COMPONENTS

Magnetic Assembly

The magnetic assembly contains all the required magnetic, thermal and structural components for the cell. Details of the assembly are as follows.

X-Y Rotating Field Coils. The rotating field is produced by two coils which are independently fabricated and subsequently bonded in assembly at 90 degrees to one another.

The X coil is innermost to the assembly and is a double sided flexible circuit having 5-mil thick copper lines, 20 mils wide and on 25 mil centers. After the basic coil configuration has been etched, it is cover coated (.5 mil polymide film), formed and bonded into an open ended rectangular tube .190 in. high, .960 in. wide and 2.610 in. long.

The circuit pattern is laid out such that circuit lines in the 2.610 direction are parallel and produce a magnetic field inside the tube which is equivalent to a wound coil with turns running in the same direction. The important feature of the flexible circuit coil is that it is an open tube and therefore substrates may be inserted or removed from the coil without having to remove any windings.

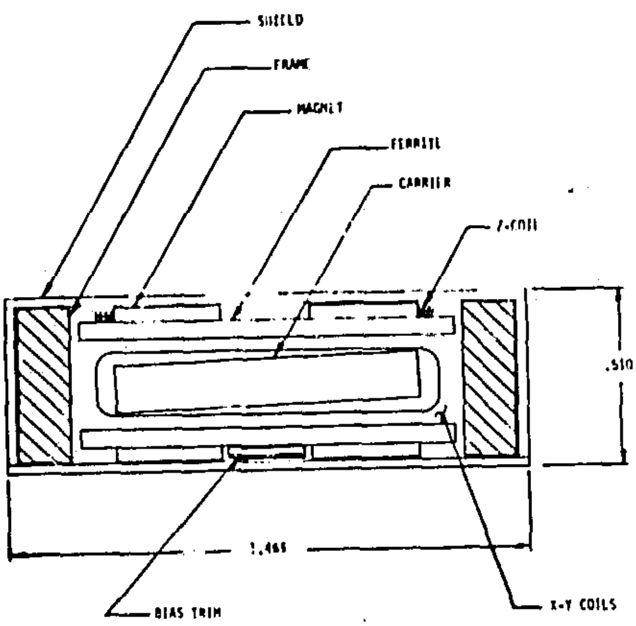
The Y coil is fabricated from rectangular polyimide insulated magnet wire 25 mils wide and 5 mils thick. This wire is wound in two layers, one above the other over a polyimide film sheet which is fixed to an expandable/collapsible rectangular mandrel. The two windings are bonded to the kapton sheet and each other using a low outgassing adhesive which is brush coated during the winding process. The two coils (X-Y) are then bonded together in alignment using a low outgassing film adhesive.

The resultant cured assembly thus provides two orthogonal coils which when driven by an out-of-phase current will produce a rotating planar magnetic field and because of the open end design, can accept substrates carrying the bubble chips.

Bias Plates and Magnets. A uniform Z bias field is provided by placing the coil subassembly between two parallel ferrite plates which spread the field produced by four rare earth ceramic magnets.

The ferrite plates and associated magnets are purchased as a precision ground, adhesively bonded assembly. The plates and magnets are held flat and parallel to within .001 inch and are furnished in demagnetized form.

Assembly of the magnet-ferrite subassemblies to the X-Y coils is performed using precision tooling which holds and locates the magnet ferrites parallel within .002 inch and centered about all three coil axes.



CELL SECTION

Frame-Coil Assembly. The cell frame is precision machined and stress relieved 6061-T6 aluminum. It is 2.950 in. long, 1.400 in. wide and .445 in. high. The front and rear mounting surfaces for the bubble chip substrate mounting are machined to a 2.6 degree angle to provide the necessary X component of the Z field. Various holes, tabs, etc., are provided for clamping the substrates, affixing the shield and mounting the cell to the memory module. The frame walls (.150 inch thick) and mounting tabs provide the conduction transfer of heat generated by the coils and substrates.

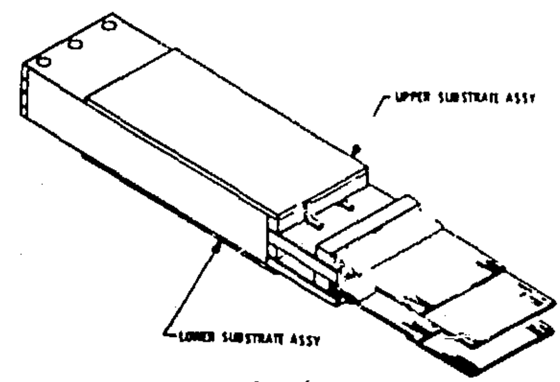
The coil/magnet ferrite assembly is precisely located and bonded into the machined frame using a high thermal conductivity low outgassing alumina filled epoxy adhesive. Again, special tooling is used to perform this operation. In order to assure an optimum thermal interface between the coils and frame walls (principal heat flow path), the high conductivity adhesive is injected through holes in the frame walls and flows and fills all along the coil edge frame interface.

A 10 turn Z bias coil is edge wound (rectangular magnet wire) and bonded in a special fixture. This coil is then bonded to the surface of the top ferrite plate which has been pre-insulated by a coating of adhesive. The coil is essentially rectangular and follows the outer perimeter of the two magnets.

The magnetic assembly shield is a precision welded and annealed high permeability .03 inch thick shell which slides over the frame and is held in place by 0-80 screws.

Carrier, Final Cell Assembly

The SSDR carrier consists of two ceramic substrates each carrying eight 100 kilobit chips. The two substrates are spaced apart by ceramic details, indium plated copper shims and are bonded together in assembly with an insulated copper cover. The carrier is inserted into the magnetic assembly along with indium plated copper shims at the frame interface. One end (outboard) of the carrier is clamped and pinned in place to provide a thermal interface and alignment. The opposite (inboard) end is lightly clamped (to allow for thermal expansion stress relief) and is aligned by the frame walls.



Carrier

Substrates

Ceramic substrates each carry eight 100 kilobit chips and 26 beam lead diodes. Thick film gold conductors 5 mils wide on 10 mil centers are used for the detectors, whereas high current lines (annihilators, generators) are wider and spaced away from the detectors. Platinum gold pads are used for solder termination of an interconnect cable to the substrate.

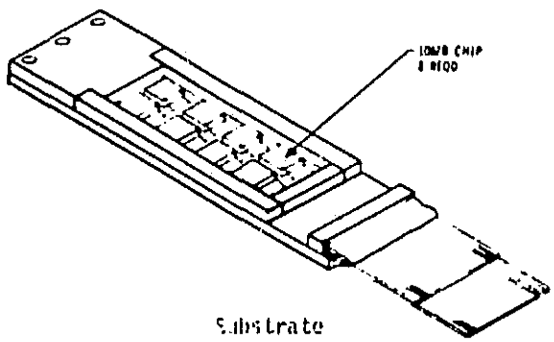
The basic substrate is a ground (flat within .001) 96 percent alumina plate .850 in. wide, 3.020 in. long and .019 in. thick. Three holes are drilled into one end of the substrate at the thermal interface. A fourth hole allows for interconnect to a copper field alignment (and shield) plate which is adhesively bonded to the back side of the substrate.

Ground substrates are fired with two levels of metallization and five levels of dielectric on the interconnect side. The first level metallization is leveled between detector lines by screening dielectric between the lines. Most vias where required are .015 in. square.

As it is required that the active chip surfaces be held parallel to copper field alignment plates, the substrate is designed with fired in place chip spacer bars which project above the substrate surface and are lapped flat after completion of firing.

A .025 in. thick beryllia plate is bonded to one end of the fired substrate to reduce the thermal gradient to the chip field. In addition, a spacer window is provided and formed by bonding .080 in. wide alumina strips around the chip field. These details and a front (inboard) alumina strip are lapped flat in assembly to provide precise alignment between substrates when the carrier is assembled.

A .004 in. thick insulated copper field alignment plate is adhesively bonded to the back of the substrate and connected by a tab soldered to the ground return conductor. A 30-line stranded wire ultra flexible cable is soldered and potted to platinum gold terminations at the substrate to memory module interface. Twenty-six beam lead diodes are pulse thermocompression bonded to pads in the detector and operator lines.



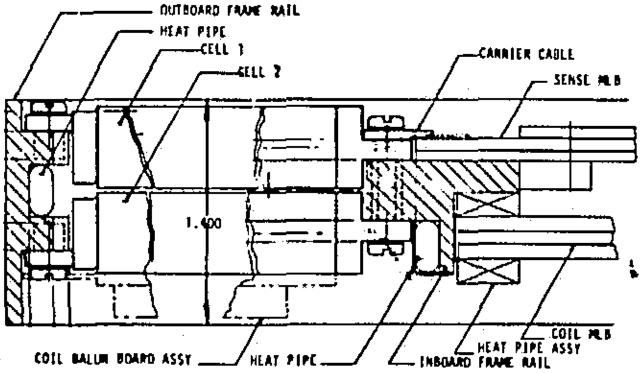
Substrate

The eight bubble chips are adhesively bonded in place using an alumina filled elastomer adhesive. Location of the chips is precisely controlled by optical alignment to precision vacuum chucks which register with the substrate edges.

Chip interconnect is via controlled geometry ultrasonically bonded aluminum ribbons for the detectors and pulse thermocompression bonded gold wires for the annihilator and generator connections.

Memory Module

The SSDR memory modules each contain 32 calls, a ten-layer sense/operator MLB and a six-layer coil driver MLB, all of which are housed in a machined and stress relieved 6061-T6 aluminum frame. Input/output to the module is via three 48 pin connectors and the two MLB's are interconnected by flexible cables at one end. The coil driver MLB can be folded out from one end to allow access to the inside surface.



CELL-MODULE SECTION

Sense Operator MLB

The ten-layer sense operator MLB carries approximately 442 components and provides for termination of the 32 cells which are arranged in groups of 16 along two sides of the MLB. Over 100 discrete resistors were replaced by ceramic thick film multi resistor packs.

Each group of 16 cells requires 960 solder terminations which are interfaced by transition cables which fan out from 25 to 50 mil centers. Controlled geometry sense matrix lines are distributed directly below their respective cell terminations and are selectively routed to the sense amplifiers so as to minimize noise injection.

Coil Driver MLB

The coil driver MLB is considerably less dense than the sense operator MLB; this being made possible by hybridizing the transistor switches in the drive circuitry.

Hybrid Circuits. The coil driver design required 48 power transistors normally available in T066 or equivalent packages which, if used, would present an unacceptable weight and volume penalty. Twenty-four hybrids, each containing two transistors, eight diodes and two resistors replaced the latter. One additional hybrid contains four transistors and four resistors. These hybrids were designed and fabricated in-house.

Cooling

Cooling of the memory modules is by conduction throughout. Relatively large amounts of power must be dissipated (coils 9 watts, hybrids 5 watts, total 50 watts). All dissipating components are adhesively bonded to surface 1100 aluminum heat rails which are up to .090 in. thick under the coil driver hybrids.

Heat Pipes

Heat pipes are used extensively within the module to reduce weight and improve thermal performance. Eight pipes are bonded to the module frame walls and are directly adjacent to the cell cooling/mounting tabs. Eight additional heat pipe assemblies are bonded on the coil driver shunt heat rails in close proximity to all power hybrids. Sixteen heat pipes arranged in pairs directly connect the memory modules to the system base plate.

Drive and Control Unit (DCU)

The DCU module controls most functions within the SSDR and contains four microprocessors, 500 integrated circuits, a RAM core memory and two PROM's. Both memory modules are connected to the DCU via stranded wire cables which are hard wired to the DCU MLB. In addition, the DCU contains all I/O interconnects. The DCU is housed in a 6061-T6 machined and stress relieved aluminum frame, which provides excess volume necessary to accommodate various power supply components mounted below. All circuitry for the DCU is carried in a single 1 ft^2 MLB and heat transfer is via surface heat rails as in the memory modules. Two heat pipes are bonded to either side of a central structural rib which shunts all heat rails at their mid-points.

Power Supply Base Plate

The power supply base plate is 50 percent occupied by commercially available modular supplies; the remaining area being utilized for I-O wiring and other supply components. This module is also machined and stress relieved 6061-T6 aluminum and serves as the structural and thermal interface for the system. Power module cooling is by conduction to the frame perimeter by a .125 in. thick section which is the bottom of the frame. A central rib flanked by two heat pipes provides an efficient heat flow path from the center of the module.